The palaeoenvironments of Kuk Swamp from the beginnings of agriculture in the highlands of Papua New Guinea

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A R T I C L E   I N F O

Article history:
Available online 22 August 2011

A B S T R A C T

Pollen, phytolith and charcoal records from the archaeological wetland site of Kuk Swamp, Wahgi Valley, Papua New Guinea spanning the period from 20,000 to 270 cal BP are compiled to reconstruct past vegetation and plant exploitation during the earliest to late phases of agricultural development. Samples collected from exposed stratigraphic sections associated with archaeological excavations enable detailed reconstructions of local vegetation and fire histories that can be directly linked to archaeological evidence for agricultural activity. The record of past environmental change is constructed through detailed chronological control and stratigraphic correlation across the swamp, revealing evidence of early Holocene vegetation disturbance including short-term, patchy forest loss and burning considered indicative of plant exploitation. It is not until the mid-Holocene (after 7000 cal BP) that persistent and widespread forest loss occurs, with burning and the transplanting of Musa banana into an open grassland environment, which is contemporary with local archaeological features representing cultivation practices. Multi-proxy palaeoecological evidence at Kuk provides a robust vegetation history and land use chronology for the Upper Wahgi Valley for the late Pleistocene and Holocene, including the emergence of an agricultural landscape by 7000 cal BP. Subsequent agricultural developments in the highlands of New Guinea can be seen as a series of continuing indigenous innovations in agricultural technology in the face of increased land degradation, climate change and external influences.

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1. Introduction

Multi-disciplinary investigations at Kuk Swamp, Wahgi Valley, Papua New Guinea have yielded direct evidence for agriculture around 7000 cal BP (Denham et al., 2003). This evidence includes archaeological features representing cultivation (Golson, 1989; Denham et al., 2004a), summary pollen and diatom records documenting the emergence of an agricultural landscape in the Upper Wahgi Valley (Denham et al., 2003, 2004b, 2009a) and phytolith and starch remains of edible plants including the exploitation of taro (Colocasia esculenta) and planting of bananas (Fullagar et al., 2006). These findings have contributed to the acceptance of the highlands of Papua New Guinea as a center of early and independent agricultural development, comparable in antiquity and complexity to other regions of independent agricultural invention around the globe (Denham, 2007a).

Over 40 years of archaeological and pollen-based investigations in the Wahgi Valley and Upper Simbu Valley have provided a spatially comprehensive, but often temporally disjointed sequence of palaeoenvironmental change from before the last glacial maximum through to the present (Fig. 1, Powell et al., 1975; Powell, 1982; Denham, 2004). Most of the sites have continuous sedimentation from approximately 5,000 years ago to the present, but prior to this date there are major gaps in the records back to the late Pleistocene. More recent analysis of samples from dated sections of the Kuk Swamp sedimentary sequence belonging to the late glacial period and the early Holocene has allowed a more complete pollen record for the basin to be constructed (Denham et al., 2003, 2004b, 2009a, 2009b). These records indicate cumulative and increasing rates of lower montane rain forest clearance from the early Holocene with dramatic degradation to a grassland landscape at 6950–6440 cal BP (Denham and Haberle, 2008; Sniderman et al., 2009). At the same time there is archaeological evidence for plant exploitation consistent with shifting
cultivation on the wetland margin from 10220–9910 cal BP (Phase 1),
mounding cultivation by 6950–6440 cal BP (Phase 2) and ditched
cultivation by 4350–3980 cal BP (Phase 3).

In order to provide a more temporally complete understanding
of the nature and extent of vegetation changes that have occurred
at Kuk Swamp since before the advent of agriculture, this paper
presents the first complete and detailed pollen record from Kuk
Swamp that includes samples that span the early (Phases 1–3) to
the late prehistoric phases (Phases 4–5/6) of agricultural activity in
the Wahgi Valley.

2. Site location

The wetland archaeological site at Kuk Swamp is located
approximately 12 km northeast of the town of Mount Hagen in the
Upper Wahgi Valley, Western Highlands Province, Papua New Guinea
(Fig. 1). Kuk is located in the Highlands, i.e., land above 1200 m above
mean sea level, at an altitude of ~1560 m. Kuk Swamp forms part of
extensive wetlands carpeting the floor of the Upper Wahgi Valley,
which is part of one of the largest inter-montane valleys in the
interior of New Guinea. The archaeological site is located on the
former Kuk Agricultural (originally Tea) Research Station that
covered ~280 ha. Approximately 100 ha of the southeast corner
were subject to multi-disciplinary investigation (Golson, 1977;
Denham et al., 2004a).

Like other wetlands in the Highlands of Papua New Guinea, Kuk
was artificially drained in the late 1960s and early 1970s for planting.
Prior to drainage some parts of the wetland were underwater except
for scattered low mounds of older, tephra-mantled lahar deposits
over and around which the wetland had accumulated (Pain et al.,

The Upper Wahgi Valley has a lower montane humid climate
with an average annual temperature of 19 °C and annual rainfall of
approximately 2700 mm (Hughes et al., 1991). Precipitation in the
valley is moderately aseasonal and dominated by local orographic
effects. Although a slight dry season occurs between May and June,
this is generally not significant enough to limit plant growth
(McAlpine et al., 1983).
3. Methods

In the field, intact stratigraphic samples were collected with minimal disturbance using square tins pushed into an exposed section and extracted. The location and survey levels of these tins were marked directly on excavation plans and stratigraphic profiles (see Fig. 1, Denham et al., 2009b). Chronological control is provided by detailed AMS $^{14}$C analysis of samples from organic remains associated with tephas and organic detritus preserved in section (Denham et al., 2003; Coulter et al., 2009). In the laboratory, 68 subsamples for pollen and charcoal analyses (2 cm$^3$ of wet sediment) were obtained; these span the pre-20,000 cal BP peats through to topsoil deposits associated with the most recent agricultural phases on the swamp (Table 1 and Fig. 2). Samples for phytolith analysis were selected from a smaller subset spanning the early phases of agricultural development (Phases 1–3).

Pollen counts are expressed as percentages of the total pollen sum. Pollen samples were divided into the following categories: trees and shrubs that are known to be common in disturbed samples for pollen and charcoal analyses (2 cm$^3$ of wet sediment) are listed by trees and shrubs that are known to be common in disturbed forest or open areas such as garden plots left for fallow (including Urticaceae/Moraceae, Trema, Acalypha and Dodonaea); herbaceous taxa comprised mainly of grass species from the family Poaceae, Asteraceae, and sedges (Cyperaceae); pteridophytes; and, aquatics. Pollen counts are expressed as percentages of the total pollen sum (excluding pollen of pteridophyte spores and aquatic vascular plants), which in most cases reaches a minimum of 250. Confidence intervals are calculated following Bennett (1994) for those taxa counted within the pollen sum. charcoal on the pollen slides (black, opaque angular which in most cases reaches a minimum of 250. Con-
and Rumex increase. Ferns and aquatics generally decrease. Phyto-
liths were not analysed for this zone. Palynological richness and
Rumex and 

**Table 1**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Sediment Description and Context (age cal BP)</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>64, 65, 66, 67, 68</td>
<td>Channel 115 (Simon’s Baret). Samples were removed from the portion of the infill underlying Tibito (Z) tephras (305–270 cal BP).</td>
<td>5/6</td>
</tr>
<tr>
<td>61, 62, 63</td>
<td>Channel 110 (Naringa’s Baret). Samples were removed from the portion of the infill underlying Olga (Q) tephras (1190–970 cal BP).</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>Pre-dates Bagala (Y) tephra (2650–1950 cal BP).</td>
<td>3</td>
</tr>
<tr>
<td>2, 3, 33, 34</td>
<td>Black clay, 10YR 1/1 to 2.5Y 2/1, structureless, massive, very firm, very plastic, very few, fine roots. Samples taken above Kim (R) tephra (3980–3630 cal BP).</td>
<td>3</td>
</tr>
<tr>
<td>60, 57, 58, 59a</td>
<td>Phase 3 palaeochannel (107) fill.</td>
<td>3</td>
</tr>
<tr>
<td>51, 52, 53</td>
<td>Early Phase 3 ditch (353) fill.</td>
<td>3</td>
</tr>
<tr>
<td>54, 55, 56</td>
<td>Early Phase 3 ditch (504) fill.</td>
<td>3</td>
</tr>
<tr>
<td>27, 28, 29, 30a, 31a, 48, 32</td>
<td>Phase 2/3 palaeochannel (103) fill.</td>
<td>2</td>
</tr>
<tr>
<td>35, 46, 36</td>
<td>Phase 2/3 palaeosurface (3004) feature fill.</td>
<td>2</td>
</tr>
<tr>
<td>37, 47, 38</td>
<td>Phase 2 palaeosurface (3009) feature fill.</td>
<td>2</td>
</tr>
<tr>
<td>39, 45, 40</td>
<td>Phase 2 palaeosurface (3026) feature fill.</td>
<td>2</td>
</tr>
<tr>
<td>40</td>
<td>Phase 2 palaeosurface (3086) feature fill.</td>
<td>2</td>
</tr>
<tr>
<td>50</td>
<td>Phase 2 palaeosurface (3089) feature fill.</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Phase 2 palaeosurface. Yellowish brown, 10YR 5/4, very fine sandy silt, very friable, nonsticky, nonplastic, considerable heterogeneity in the colour of this unit in the field. Samples taken above “R-W ash” deposit dated to 6440–5990 cal BP.</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Phase 2 palaeosurface. Black clay, 10YR 2/1 to 2.5Y 2/1, structureless, massive, very firm, very plastic, very few, very fine roots, mixed with dark grey clay, 10YR 4/1, massive, firm, very sticky, very plastic, few fine roots, with very dark grey (gley 3/N) and dark brown (7.5YR 3/3) mottles, latter represents ferric iron deposition. Sample associated with Phase 2 palaeo-surface features dated to 6950–6440 cal BP.</td>
<td>2</td>
</tr>
<tr>
<td>6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17</td>
<td>Dark grey, 10YR 4/1, clay, massive, firm, very sticky, very plastic, few fine roots, with very dark grey (gley 3/N) and dark brown (7.5YR 3/3) mottles, latter represents ferric iron deposition. Upper level samples associated with dated sample (OZD 931, 7420–7210 cal BP). Base of grey clay unit is dated to between 10220–9910 cal BP.</td>
<td>1</td>
</tr>
<tr>
<td>18, 19, 20</td>
<td>Palaeochannel (101b) fill. Very dark grey, 10YR 3/1, structureless, massive, clay, very firm, very sticky, very plastic, many fine roots, homogeneous.</td>
<td>1</td>
</tr>
<tr>
<td>25, 26, 41</td>
<td>Phase 1 palaeosurface feature (1401) fill.</td>
<td>1</td>
</tr>
<tr>
<td>42, 43, 44</td>
<td>Phase 1 palaeosurface feature (1404) fill.</td>
<td>1</td>
</tr>
<tr>
<td>21, 22</td>
<td>Phase 1 palaeochannel (101a) fill. Upper section is black, 5Y 2/1, structureless, massive, organic rich - silt loam, firm, slightly sticky, slightly plastic, few very fine roots, considerabile heterogeneity with some samples being very dark brown, 10YR 2/2, structureless, massive, silty loamy peat, very friable, slightly sticky, slightly plastic, many medium and common very fine roots with fine granules (10YR 5/6, yellowish brown and 2.5Y 7/6, yellow) of tephra and soil aggregates. Lower section is very dark greyish brown, 2.5Y 3/2, lenticular laminations, organic clay loam, friable, slightly sticky, slightly plastic, common large and few very fine roots; fine granules of fine silty sand (2.5Y 5/4, light olive brown, with interior of granules grading to 7.5YR 4/6, strong brown), heterogeneous with organic and inorganic lenses clearly visible, well-preserved leaves and other organic materials and oxidation of vivianite on exposure. Samples taken above basal ages of fill dated to between 10220–9910 cal BP.</td>
<td>1</td>
</tr>
<tr>
<td>23, 24</td>
<td>Pleistocene peat. Late glacial peats probably dated to pre-20,000 cal BP.</td>
<td>1</td>
</tr>
</tbody>
</table>

* Samples excluded from Figs. 2–5 due to unclear provenance based on pollen assemblage (i.e. likely to contain significant reworked pollen, see Denham et al., 2009a).

b Cant reworked pollen, see Denham et al., 2009a.

b Denham et al., 2003.

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5. Trends in vegetation, climate and human activity

The inhabitants of the Upper Wahgi valley during the Late Pleis-
tocene inhabited a largely forested valley floor, with the prominence of Nothofagus dominated upper montane forests and mixed lower montane forest (with greater frequencies of Castanopsis/Lithocarpus) fluctuating in concert with climate change (zones Kuk–1 to Kuk–3, see also Denham and Haberle, 2008). The presence of open grasslands and episodes of burning around Kuk Swamp for at least the last 20,000 years suggests that conditions were suitable for ignition either from natural processes (e.g. lightning) or human agency throughout this time. Similar records of Late Pleistocene burning and formation of open grassland habitats are to be found in the Tari Basin (Haberle, 1998) and Kosipe (Hope, 2009), where there is evidence of Late Pleistocene human occupation that is suggestive of human activity driving the maintenance and possibly formation of intermontane...
**Fig. 2.** Stratigraphic summary of Kuk Swamp adapted from Coulter et al. (2009: Fig. 4). The age (cal BP) of selected tephras and palaeo-features bounded the relative age of palaeo-samples (numbers 1-68) listed to the right of the stratigraphic column (see Table 1). The relationship of palaeo-samples to archaeological phases is also illustrated. Photographs of excavated features from different agricultural phases (1 and 3) taken by K. Gollan in 1975 (upper) and E.C Harris in 1977 (lower) and reproduced courtesy of Jack Golson.

**Fig. 3.** Summary pollen diagram for Kuk Swamp with phytolith counts from selected samples expressed as percentages of their total sum (Sum = forest + herbaceous taxa, excluding spores and aquatic vascular plants). The relative chrono-stratigraphic order of the 68 samples (with ages, stratigraphy and phases; from Fig. 2), percentages of major pollen groups and phytolith taxa, microcharcoal (%) and rarefraction index are presented. Numerical zonation is derived from the pollen taxa making up the total pollen sum.
Fig. 4. Composite pollen diagram for Kuk Swamp. Confidence intervals (95%) for taxa included within the pollen sum are calculated following Bennett (1994) and significant pollen zones are determined using binary splitting by sum-of-squares analysis (Bennett, 1996). a. Rainforest taxa are expressed as percentages of the total pollen sum. b. Woody non-rainforest and herbaceous taxa expressed as percentages of the total pollen sum. Selected phytolith taxa are expressed as percentages of the total phytolith sum. Gaps in the phytolith record are a result of not having all levels analysed for phytoliths. c. Fern spores and aquatic vascular plants lie outside the pollen sum and are expressed as percentages of the total pollen sum.
Fig. 4. (continued).
valley grasslands. In contrast to these pollen records at these locations, where early Holocene warming and increased precipitation led to forest encroachment into Late Pleistocene grasslands, the Kuk Swamp record shows a more muted advance of forest and the persistence of a mosaic of grassland and forested habitats under episodic burning.

What were people doing at Kuk Swamp to restrict the advance of forest due to rapid and significant climate change during the Terminal Pleistocene? In addition to faunal resources, the landscape offered ready access to the nutritious members of the high-altitude Pandanus brosimos/iwen/jiulianettii complex (Stone, 1982), as well as to diverse arboreal resources of the lower montane forests (Golson, 1991). Rather than merely passively gathering resources, people were opening up patches in the forest using fire and arguably used stone tools to ring-bark trees and assist with the clearing of understory vegetation (Groube, 1989). Although the evidence is scant, people plausibly focused on gaps in the forest canopy, such as those caused by tree-fall and landslides, as well as riparian and wetland ecotones, where resources may have been different and potentially more diverse than those found under the forest canopy (Denham and Barton, 2006; Denham and Haberle, 2008). Some gaps in the forest were maintained through burning and clearing, and patches of grassland formed, potentially adjacent to wetlands and along riparian corridors, due to localized and sustained forest disturbance. As patches became maintained foci of activity, so too the resources within those gaps — including herbs (Musa spp.), tuberous plants (potentially including taro and yams), grasses (Saccharum spp. and Setaria palmifolia), and a wide variety of leafy vegetables — were brought under increasing management. At this time, people are inferred to have engaged in extensive hunting and foraging activities to sustain broad-spectrum diets. Although people may not have resided permanently within the Upper Wahgi Valley at this time, it has been argued that mobile groups lived permanently within the forested interior of New Guinea during the Pleistocene (Denham, 2007b; Summerhayes et al., 2010).

Between 10,200 cal BP and 7000 cal BP and during deposition of a distinctive grey-brown clay on the wetland margin, grasslands and fern flora increase at the expense of forest, which continues to be

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### Table: Pollen Zones

<table>
<thead>
<tr>
<th>SAMPLE No.</th>
<th>FERN SPORES</th>
<th>AQUATICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuk-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kuk-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kuk-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kuk-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kuk-1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Fig. 4. (continued)
under the influence of periodic fire. At the same time, the catchment forest composition changes from dominance of montane canopy taxa, such as *Nothofagus*, *Castanopsis/Lithocarpus* and gymnosperms to subcanopy taxa, particularly *Pandanus*. During the early Holocene, the floor and walls of the Upper Wahgi Valley were carpeted with increasingly disturbed lower montane forests and mid to upper montane forest had retreated to the ridgelines, peaks and higher valley walls above 2000 m (Denham and Haberle, 2008). Forest disturbance was variable, producing a mosaic landscape with locally encroaching patches of grassland and secondary forest subject to more persistent disturbance using fire and stone tools. The archaeobotanical record indicates the processing of taro and yam at Kuk from 10,200 cal BP (Fullagar et al., 2006). As plant exploitation became more focused on maintained patches and swidden plots, people’s mobility may have decreased (cf. Denham and Barton, 2006). Even though they need not have lived a sedentary life, people’s general mobility may have decreased in order to invest more time and labour in the maintenance of increasingly important and spatially fixed resources. People continued to engage in extensive activities, such as the foraging evidenced by the *Pandanus antaresensis*-dominated archaeobotanical assemblage at Manim (Donoghue, 1989), as well as long-distance and long-duration hunting and foraging expeditions to higher and lower altitudes, witnessed at Kosipe (Summerhayes et al., 2010). However, a greater percentage of people’s time was plausibly spent managing, harvesting and consuming resources within more limited areas around maintained patches and swidden plots.

The most dramatic change in the pollen record occurs at the beginning of the mid-Holocene, at around 7000 cal BP (zone Kuk-4), when there is a rapid loss of forest associated with increased and persistent burning and a permanent open grass-sedge swampland is established. The palaeoeccological evidence from Kuk, in conjunction with palaeoenvironmental records from Draepi-Minjigina, Lake Ambra and Warrawau, suggests that forest clearance, widespread use of fire and the establishment and maintenance of disturbed environments were regional processes across the Upper Wahgi Valley from at least 7000 cal BP (Denham and Haberle, 2008). Taken in conjunction with archaeological evidence for prehistoric mounding at Kuk, Mugumamp and Warrawau (Denham and Haberle, 2008), this vegetation history represents the establishment of an agricultural landscape in the Upper Wahgi Valley by the mid-Holocene. As well as engaging in extensive foraging and gathering, and swidden cultivation, the earliest evidence of more intensive forms of plant exploitation emerged during the mid-Holocene. The bases of mounds used for cultivation date to 7000–6500 cal BP along the wetland edge at Kuk, with more recent pre-c. 4500 cal BP finds at Warrawau (Golson, 2002) and Mugumamp (Harris and Hughes, 1978). Although preserved at wetlands, mound cultivation may also have occurred in dryland locations at this time. A possible indication that the increased grass pollen percentages of zone Kuk-4 suggests an expansion of dryland grasslands on the newly cleared slopes around the swamp. Further evidence comes from the sustained high percentages of grass phytoliths and the small representation of palms/ginger phytoliths over the same time, suggesting stability in abundance of local swamp grasses and replacement of palms and/or gingers, possibly growing as understory vegetation on the slopes, by grasses (Fig. 4b). This is corroborated by evidence for more extensive dryland grasslands after c. 4000 cal BP on the floor of the Upper Wahgi Valley (Denham et al., 2009b; Sniderman et al., 2009).

Following several thousand years of persistent forest disturbance for various forms of plant exploitation, the majority of the valley floor and slopes were degraded to grassland. Only isolated pockets of disturbed forest survived within the valley, with stands of heavily utilized primary forest surviving on the higher slopes above 2000 m. The extensive grasslands carpeting the floor of the valley were periodically burned and would have been depauperate in large-to-medium sized mammals and edible plants (Golson, 1982). Within this highly degraded, but intensively settled landscape, people had less access to land for swidden cultivation and foraging. Although these activities were still likely to be practiced by people living on the valley floor, they became increasingly reliant on intensive forms of dryland cultivation, plausibly using mounds and other forms of raised bed cultivation on valley slopes (Powell et al., 1975), as well as upon ditched field systems in the wetlands and eventually upon Casuarina tree-fallowing (Haberle, 2007). Several wetlands in the Upper Wahgi Valley (Kana, Kuk, Warrawau) and adjacent regions (Haeapugua, Tambul) were drained for cultivation, and some had already been periodically or episodically drained for centuries by 2500 cal BP. Current evidence suggests that these developments were indigenous (Denham, 2005). Not only would the drainage of...
wetlands to create ditched field systems have greatly increased the area available for cultivation, but the drained land, particularly compared with heavily weathered valley slopes, would have been extremely fertile, amenable to cultivation for several years without fallow and relatively resistant to the increased frequency of ENSO-induced droughts.

The last 1200 cal yrs at Kuk Swamp is marked by an increase in Urticaceae pollen, a family that contains both woody and herbaceous species, which has been shown to be an indicator of early regrowth forest and gardens (Powell, 1970). Increases in Urticaceae within the last 2000 years are recorded across a number of pollen records in the Wahgi Valley (Draepi-Minjigina, Lake Ambra and Warrawau, Powell, 1970) and are most likely related to the expansion of weedy plants in an increasingly degraded and intensively utilised agricultural landscape. This may also be an indicator of a longer term trajectory of innovation and adaptation strategies that alleviated the consequences of forest loss and subsequent soil nutrient depletion. These strategies include the possible development of soil tillage around 2500 cal BP (Golson, 1977, 1982; Bayliss-Smith, 2007), Casuarina agroforestry techniques around 1200 cal BP (Haberle, 1994; Haberle and Atkin, 2005) and raised-bed cultivation sometime between 1000 and 500 years ago (Bayliss-Smith, 2007). A shift to shorter fallow times may have altered the dominance of vegetation cover around Kuk Swamp towards early regrowth woody and herbaceous plants, such as Urticaceae. In the case of deliberate planting of Casuarina, this development would have facilitated shorter fallow times through nitrogen-fixation in nutrient depleted soils and removed the need for further forest destruction for timber, thereby reducing the resource loss that such destruction entailed (Bourke, 1997).

6. Extra-regional influence, intensification and local innovation

What does the Kuk Swamp record mean in terms of the nature and origin of agriculture in highland New Guinea? The palaeoecological records currently available from highland valleys point to a sustained and gradual intensification of forest clearance and burning from at least 7800 cal BP (Haberle, 2007); the earliest evidence coming from the Baliem Valley pollen record, some 800 years before the same changes are registered in the Kuk Swamp record (Haberle et al., 1991). The timing for first clearance of valley forest is shown to be neither strictly time-transgressive nor is it synchronous along a longitudinal transect in the highlands, as might be expected under a ‘Neolithic Transition’ model where diffusion of agricultural techniques and crops was rapid and the impacts widespread (Haberle, 2003). If agriculture was being practiced around 10,000 cal BP in the Wahgi Valley, as suggested from the archaeological evidence at Kuk Swamp (Golson, 1991, 2007; Denham et al., 2004a), then this does not register in the local palaeoecological record until 3000 years later. This suggests that either the agricultural activity was very localised for a long period of time and not registered in regional pollen records, or that the antiquity of early agriculture in New Guinea requires reassessment. A number of critical lines of evidence from the Kuk Swamp excavations have been challenged by Denham (2005) and Denham et al. (2009a,b) that suggest that the basal features at the site are not necessarily associated with agricultural practices. Recent assessments of the possible origins of agriculture have emphasised the possibility of both in situ adaptations and invention, overlain by diffusion of domestic plant and animals from lower altitudes in New Guinea or from sources further afield. Is it possible that agriculture was transferred from the lowlands to the highlands during the late glacial to early Holocene period? Lentfer et al. (2010) report evidence for lowland rainforest gap maintenance and promotion of favorable plants in the coastal region of Papua New Guinea during the late glacial and suggest the possibility of earlier deliberate selection and management of Musa banana and crops such as taro, and their subsequent transfer into the highlands. However, there remains insufficient evidence from either Kuk, or the coast to make definitive and more conclusive arguments on this matter.

A more complex model of landscape history is necessary to adequately account for the emerging evidence for agricultural practices across the island of New Guinea. A detailed re-evaluation of the existing palaeoecological dataset for New Guinea (Haberle, 2003, 2007 and Denham and Haberle, 2008), has been interpreted to reflect a trend from quiescent impact (late glacial to early Holocene) towards an increasingly dynamic impact (mid-late Holocene) of human activity that is punctuated by peak episodes of vegetation change towards a more open landscape (7000–6500, 4500–4000, and 1500–1000 cal BP). Whether these latter episodes of rapid vegetation change are directly associated with the introduction of cultivars (e.g., a hypothesised introduction of taro 4500 years ago, Bayliss-Smith, 1996), or indigenous developments in agricultural techniques in the face of increased land degradation or climate change (e.g., a hypothesised prolonged drought forcing the development of Casuarina agroforestry techniques around 1200 years ago, Haberle and Chestpohl-Lusty, 2000), is not yet known for certain. While the timing and nature of these changes can be identified, research is yet to understand the reasons for these changes.

7. Conclusions

The story of agricultural development in the highlands of New Guinea is one of continuing indigenous innovation in agricultural techniques in the face of increased land degradation and climate change. Increased climate variability during the mid to late Holocene, soil nutrient depletion and pressure on limited resources may all have been primary drivers for ongoing innovation and agricultural development in the highlands. Further insights into how agriculture transformed these highland valleys can be gained through application of new approaches such as high-resolution sampling and multi-proxy palaeoenvironmental reconstructions. These insights bring us one step closer to understanding how people adapted to major environmental perturbations such as changing climates and land degradation.

Acknowledgements

We thank Jack Golson and Geoff Hope for the many years of inspirational discussion and support during our work in Papua New Guinea. This was written while SH was a Senior Research Fellow at the ANU, CL has been supported by an Australian Research Council funding, SO was a Masters student at ANU and TD was supported by a Monash Research Fellowship.

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